It follows that the amplitude of any term in a sine curve deduced from only a moderate number of observations must be received with caution until an investigation of its probable error has been made, and this remark refers especially to the second and higher terms where the amplitudes are so often small.

W. H. DINES.

Benson Observatory, Wallingford, July 29.

ON THE CHARACTER OF THE "S" SOUND.

SOME two years ago I asked for suggestions as to the formation of an artificial hiss, and I remarked that the best I had then been able to do was by blowing through a rubber tube nipped at about half an inch from the open end with a screw clamp, but that the sound so obtained was perhaps more like an *f* than an *s*. "There is reason to think that the ear, at any rate of elderly people, tires rapidly to a maintained hiss. The pitch is of the order of 10,000 per second."[1] The last remark was founded upon experiments already briefly described[2] under the head "Pitch of Sibilants."

> Doubtless this may vary over a considerable range. In my experiments the method was that of nodes and loops (*Phil. Mag.*, vol. vii., p. 149 (1879); Scientific Papers, I., p. 406), executed with a sensitive flame and sliding reflector. A hiss given by Mr. Enock, which to me seemed very high and not over audible, gave a wave-length (λ) equal to 25 mm., with good agreement on repetition. A hiss which I gave was graver and less definite, corresponding to $\lambda = 32$ mm. The frequency would be of the order of 10,000 per second, more than 5 octaves above middle C.

Among the replies, publicly or privately given, with which I was favoured, was one from Prof. E. B. Titchener, of Cornell University,[3] who wrote:—

> Lord Rayleigh's sound more like an *f* than an *s* is due, according to Köhler's observations, to a slightly too high pitch. A Galton whistle, set for a tone of 8400 v.d., will give a pure *s*.

It was partly in connection with this that I remarked later[4] that I doubted whether any pure tone gives the full impression of an *s*, having often experimented with bird-calls of about the right pitch. In my published papers I find references to wave-lengths 31·2 mm., 1·304 in. = 33·1 mm., 1·28 in. = 32·5 mm.[5] It is true that these are of a pitch too high for Köhler's optimum, which at ordinary temperatures corresponds to a wave-length of 40·6 mm., or 1·60 inches; but they agree pretty well with the pitch found for actual hisses in my observations with Enock.

Prof. Titchener has lately returned to the subject. In a communication to the American Philosophical Society[6] he writes:—

> It occurred to me that the question might be put to the test of experiment. The sound of a Galton's whistle set for 8400 v.d. might be imitated by the mouth, and a series of observations might be taken upon material composed partly of the natural (mouth) sounds and partly of the artificial (whistle) tones. If a listening observer were unable to distinguish between the two stimuli, and if the mouth sound were shown, phonetically, to be a true hiss, then it would be proved that the whistle also gives an *s*, and Lord Rayleigh would be answered.
>
> The experiment was more troublesome than I had anticipated; but I may say at once that it has been carried out, and with affirmative result.

A whistle of Edelmann's pattern (symmetrical, like a steam whistle) was used, actuated by a rubber bulb; and it appears clear that a practised operator was able to imitate the whistle so successfully that the observer could not say with any certainty which was which. More doubt may be felt as to whether the sound was really a fully developed hiss. Reliance seems to have been placed almost exclusively upon the position of the lips and tongue of the operator. I confess I should prefer the opinion of unsophisticated observers judging of the result simply by ear. The only evidence of this kind mentioned is in a footnote (p. 328): "Mr. Stephens' use of the word 'hiss' was spontaneous, not due to suggestion." I have noticed that sometimes a hiss passes momentarily into what may almost be described as a whistle, but I do not think this can be regarded as a normal *s*.

Since reading Prof. Titchener's paper I have made further experiments with results that I propose to describe. The pitch of the sounds was determined by the sensitive flame and sliding reflector method, which is abundantly sensitive for the purpose. The reflector is gradually drawn back from the burner, and the positions noted in which the flame is unaffected. This phase occurs when the burner occupies a *node* of the stationary waves. It is a place where there is no to and fro *motion*. The places of recovery are thus at distances from the reflector which are (odd or even) multiples of the half wave-length. The reflector was usually drawn back until there had been five recoveries, indicating that the distance from the burner was now $5 \times \frac{1}{2}\lambda$, and this distance was then measured.

The first observations were upon a whistle on Edelmann's pattern of my own construction. The flame and reflector gave $\lambda = 1{\cdot}7$ in., about a semi-tone flat on Köhler's optimum. As regards the character of the sound, it seemed to me and others to bear some resemblance to an *s*, but still to be lacking in something essential. I should say that since my own hearing for *s*'s is now distinctly bad, I have always confirmed my opinion by that of other listeners whose hearing is good. That there should be some resemblance to an *s* at a pitch which is certainly the predominant pitch of an *s* is not surprising; and it is difficult to describe exactly in what the deficiency consisted. My own impression was that the sound was too nearly a pure tone, and that if it had been quite a pure tone the resemblance to an *s* would have been less. In subsequent observations the pitch was raised through

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[1] NATURE, vol. xci., p. 319, 1913.

[2] *Phil. Mag.*, vol. xvi., p. 235, 1908. Scientific Papers, V., p. 486.

[3] NATURE, vol. xci., p. 451, 1913.

[4] NATURE, vol. xci., p. 558, 1913.

[5] Scientific Papers, I., p. 407; II., p. 100.

[6] Proceedings, vol. liii., August—December, 1914, p. 323.

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λ = 1·6 in., but without modifying the above impressions.

Wishing to try other sources which I thought more likely to give pure tones, I fell back on bird-calls. A new one, with adjustable distance between the perforated plates, gave on different trials λ = 1·8 in., λ = 1·6 in. In neither case was the sound judged to be at all a proper *s*, though perhaps some resemblance remained. The effect was simply that of a high note, like the squeak of a bird or insect. Further trials on another day gave confirmatory results.

The next observations were made with the highest pipe from an organ, gradually raised in pitch by cutting away at the open end. There was some difficulty in getting quite high enough, but measures were taken giving λ = 2·2 in., λ = 1·9 in., and eventually λ = 1·6 in. In no case was there more than the slightest suggestion of an *s*.

As I was not satisfied that at the highest pitch the organ-pipe was speaking properly, I made another from lead tube, which could be blown from an *adjustable* wind nozzle. Tuned to give λ = 1·6 in., it sounded faint to my ear, and conveyed no *s*. Other observers, who heard it well, said it was no *s*.

In all these experiments the sounds were *maintained*, the various instruments being blown from a loaded bag, charged beforehand with a foot blower. In this respect they are not fully comparable with those of Prof. Titchener, whose whistle was actuated by squeezing a rubber bulb. However, I have also tried a glass tube, 10·4 in. long, supported at the middle and rubbed with a resined leather. This should be of the right pitch, but the squeak heard did not suggest an *s*. I ought perhaps to add that the thing did not work particularly well.

It will be seen that my conclusions differ a good deal from those of Prof. Titchener, but since these estimates depend upon individual judgment, perhaps not uninfluenced by prepossessions, they are not fully satisfactory. Further independent aural observations are desirable. I fear a record, or ocular observation, of vibrations at so high a pitch is hardly feasible.

I may perhaps be asked if a characteristic *s*, having a dominant pitch, is not a pure tone, what is it? I am disposed to think that the vibration is irregular. A fairly defined pitch does not necessitate regular sequences of more than a few (say 3–10) vibrations. What is the state of affairs in an organ-pipe which does not speak well, or in a violin string badly bowed? An example more amenable to observation is afforded by the procession of drops into which a liquid jet breaks up. If the jet is well protected from outside influences, the procession is irregular, and yet there is a dominant interval between consecutive drops, giving rise under suitable conditions to a sound having a dominant pitch. Vibrations of this sort deserve more attention than they have received. In the case of the *s* the pitch is so high that there would be opportunity for interruption so frequent that they would not be separately audible, and yet not so many as to preclude a fairly defined dominant pitch. I have an impression, too, that the *s* includes subordinate components decidedly graver than the dominant pitch.

Similar questions naturally arise over the character of the *sh, f,* and *th* sounds.

RAYLEIGH.

GAUGES.

INTERCHANGEABILITY forms the basis of manufacture wherever there are a large number of articles to be made, and the processes required in order to secure it are well understood. The system makes it possible to subdivide the manufacture of any part into many small processes, each effected by one worker, aided by machine or hand tools, who acquires great skill in his particular operation. The parts so made must be capable of being assembled with the minimum labour; in fact, assembling ought to consist merely of putting together parts selected at random from stocks of details, with the certainty that these will fit without any additional tool work on the part of the assembler. Each operation performed in the making of any part must give to that part definite dimensions within prearranged limits. The precise dimensions and limits are chosen with a view to securing running, push, driving, or shrinking fits, according as will be required in the assembling operations. Gauges by means of which the results of each operation may be tested thus become a necessity in the manufacture of interchangeable parts. These gauges are generally of the limit form. Very large numbers of these gauges are required in the production of munitions.

Suppose the operation to consist of boring a hole nominally 1 in. in diameter, and that the finished hole must not exceed 1·003, nor be less than 0·997 in. in diameter. The gauge employed would be cylindrical, having one end 1·003, and the other end 0·997 in. in diameter. If the smaller end can go into the hole, the hole is not less than 0·997 in. in diameter, and if the larger end cannot go in, the hole is not larger than 1·003 in. diameter. By use of a gauge of this kind, any workman of ordinary intelligence may produce work having a high degree of accuracy.

It is obvious that the gauges employed must be much more accurate in dimensions than the work which they are employed to check. Thus the gauge mentioned above would have its larger end probably within the limits 1·0031 and 1·0029, the variation permitted being one ten-thousandth inch above or below the rated size. Further, gauges must be made of very hard material in order to reduce wear, and must have well-finished surfaces. The hard steel used for this purpose is often of such quality as to require annealing once or twice before the necessary machining operations can be completed. After machining nearly to the finished size, the gauge is hardened, a process which generally warps the material.

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